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Published in:
Journal of Pain

DOI:
10.1016/j.jpain.2019.01.002

Accepted Manuscript

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PII: S1526-5900(19)30028-8
DOI: https://doi.org/10.1016/j.jpain.2019.01.002
Reference: YJPAI 3679

To appear in: *Journal of Pain*

Received date: 22 June 2018
Revised date: 21 December 2018
Accepted date: 6 January 2019

Please cite this article as: Caroline Blais , Daniel Fiset , Hana Furumoto-Deshaies , Miriam Kunz , Dominik Seuss , Stéphanie Cormier , Facial features underlying the decoding of pain expressions, *Journal of Pain* (2019), doi: https://doi.org/10.1016/j.jpain.2019.01.002

Facial features underlying the decoding of pain expressions

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Disclosure:

This work was supported by a grant from the Social Sciences and Humanities Research Council (SSHRC) to Caroline Blais, Daniel Fiset, Stéphanie Cormier and Miriam Kunz, and by an undergraduate scholarship from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Hana Furumoto-Deshaies. The authors have no conflict of interest to declare.

Abstract

Previous research has revealed that the face is a finely tuned medium for pain communication. Studies assessing the decoding of pain facial expressions have revealed an interesting discrepancy, namely that despite "eyes narrowing" being the most frequent facial expression accompanying pain, individuals mostly rely on "brow lowering", "nose wrinkling/upper lip raising" to evaluate pain. The present study verifies if this discrepancy may reflect an interaction between the features coding pain expressions and the features used by observers and stored in their mental representations. Exp. 1 shows that more weight is allocated to the "brow lowering" and "nose wrinkling/upper lip raising", supporting the idea that these features are allocated more importance when mental representations of pain expressions are stored in memory. These two features have been associated with negative valence and with the affective dimension of pain, whereas the "eyes narrowing" feature has been associated more closely with the sensory dimension of pain. However, Exp. 2 shows that these two features remain more salient than "eyes narrowing" even when attention is specifically directed towards the sensory dimension of pain. Together, these results suggest that the features most saliently coded in the mental representation of pain facial expressions may reflect a bias towards allocating more weight to the affective information encoded in the face.

Keywords: Facial expression, Decoding, Pain, Pain dimensions

Perspective: This work reveals the relative importance of three facial features representing the core of pain expressions during pain decoding. The results show that two features are over-represented; this finding may potentially be linked with the estimation biases occurring when clinicians and lay persons evaluate pain based on facial appearance.

1. Introduction

Communicating pain to others increases the likeliness that one will receive help [20]. Facial expression is very effective with respect to that endeavor [66]. In fact, a set of facial movements has been observed to occur under various pain conditions [43] with enough consistency to allow the recognition of pain in others [31,39,44,58]. This set includes “brow lowering”, “tightening and closing of the eyelids”, and “nose wrinkling/upper lip raising” [43,45,46]. The specific combination in which these movements appear in the face of someone experiencing pain is however subject to individual variations [29], with “tightening and closing of the eyelids” being the most frequently observed feature across individuals [9,29]. Although a substantial body of knowledge has been developed on how pain is coded through facial expressions, little is known about the visual strategies underlying the decoding of facial expressions of pain and, more specifically, what facial features individuals rely on to interpret the pain experienced by another.

Current models of visual perception suggest that the decoding of an object in the outside world depends on the information available in a stimulus, and on the mental representation of that object in memory [17]. The intersection between the available information and the mental representation determines what visual information will be efficiently used by an individual to recognize the object [17]. Thus, according to this conceptualization of visual perception, the recognition of an object involves three components: (i) the visual information contained in the object, (ii) the mental representation of the object in memory, and (iii) the visual information extracted from the object in order to recognize it. With regards to facial expressions of pain, two of these components have been studied already: the first component, i.e. the visual information contained in the facial expressions [e.g. 28,31,39,43,44,45,46,58], and the third component, i.e. the visual information extracted from them [e.g. 36,56]. No study, however, has looked into the mental representations of facial expressions of pain (second component).

Interestingly, a discrepancy has been observed between the available information in facial expressions of pain (i.e. first component) and the visual information used to recognize them (i.e. third component). As mentioned above, studies on the available information suggest that the “eye narrowing” feature is the most prominent cue [9,29]. However, studies investigating the visual information used to recognize the expressions have shown that the “brow lowering” feature better predicts the amount of pain perceived by an observer [36]; and that individuals rely mostly on the mouth and on the “brow lowering” feature when discriminating pain from other basic emotions [55]. In other words, the discrepancy highlighted above suggests that while more information is available in the “eye narrowing” feature (first component), individuals mostly rely on the visual information contained in the “nose wrinkling/upper lip raising” and the “brow lowering” features (third component). This discrepancy may lie in the way individuals store facial expressions of pain in their mental representations (second component). The present study will empirically measure the relative weight allocated to these three facial features in the mental representation of facial expressions of pain.

2. Experiment 1

The Reverse Correlation technique [1, 2] was used. This technique comes from psychophysics, and has been used in many different fields of vision research, from low-level [e.g. 7, 15, 36] to high-level vision [e.g. 12, 18, 33, 57], in order to measure the mental representations individuals build in memory about their visual world. Interestingly, the mental representation one builds of an object from the outside world does not necessarily perfectly overlap with the physical appearance of the actual object [e.g. 15, 17]. Take for instance the mental representation of other-group faces: studies have shown that individuals represent the facial appearance of someone more positively when they come from the same social group than when they come from another social group [12, 37, 53]. In other words, for the same physical information available, the mental representation differs from one social group to another.

With regard to the recognition of pain facial expressions, this technique may allow to better understand the observation that while the “eye narrowing” feature is the most frequently observed, the “brow lowering” and “nose wrinkling/upper lip raising” are the features most individuals rely on. In fact, it is possible that when individuals build their mental representations of pain facial expressions, they emphasize the visual information contained in the “brow lowering” and “nose wrinkling/upper lip raising”, thus increasing the importance of these features when it comes to recognizing pain in others. The Reverse Correlation technique will thus allow to verify if some features are overrepresented compared with others in mental representations of pain facial expressions. Most importantly, the Reverse Correlation technique makes no *a priori* assumption about how the three aforementioned facial features are related to perception. In fact, as explained in more details below, the appearance of the stimulus is manipulated on a trial-by-trial basis by randomly varying each pixel’s luminance.

2.1 Experiment 1a.

2.1.1 Method.

2.1.1.1 Participants. Twenty White participants (14 women; mean age of 21.5 years-old; SD of 3.1) took part in the experiment. The protocol of this experiment was approved by the Research Ethics Committee of Université du Québec en Outaouais and was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). All participants provided informed written consent. All participants had normal or corrected-to-normal visual acuity. All procedures were carried out with the ethics approval of the Université du Québec en Outaouais. The sample size was determined *a priori* based on the typical sample size used with the Reverse Correlation method. This allows for a statistical power of 0.8 (as measured with G*Power) to observe an effect size of 0.3 with a repeated-measure ANOVA, as will be performed in the present study.

2.1.1.2 Material and stimuli. Stimuli were displayed on a calibrated LCD monitor with a resolution of 720p and a refresh rate of 60 Hz. The experimental program was written in Matlab, using functions from the Psychophysics toolbox [5, 38].

A Reverse Correlation technique consists in adding sinusoidal white noise over a face in order to modify its appearance, and asking participants to make a judgement based on the face's final appearance. The idea behind the method is that when the noise modifies the appearance in a way that fits with the mental representation (e.g. when the noise modifies a face such that its expression corresponds more closely to what a facial expression of pain looks like in the observer's mind), the participant will judge the stimulus accordingly (e.g. as displaying an expression of pain). Thus, following a minimum of 300 trials [6] in which patches of noise are created randomly and added to a base face, it is possible to infer what visual properties of the noise fit with the mental representation of a stimulus category (e.g. a facial expression of pain). One of the most important benefits of the Reverse Correlation technique is that it does not rely on any *a priori* assumption with regard to which facial feature is important for the task. Indeed, the facial features themselves are not manipulated: their appearance is modified through the random variation in luminance of all the pixels contained in the image.

In the present study, the technique was thus used to reveal the participants' mental representation of the facial expression of pain. The procedure to create a stimulus is presented in Figure 1, along with three stimulus examples. The same base face was used across all trials. It consisted in the grayscale picture of a White male avatar in which the action units 4, 6/7, and 9/10, respectively representing "brow lowering", "lids tightening" and "nose wrinkling/upper lip raising", were slightly and equally activated. The decision to use a base face containing some signal in the three facial features typically observed in pain facial expressions was made to constrain the stimulus space, as suggested by

[6]. Nevertheless, the Reverse Correlation technique may be used without any signal [18]. Moreover, even when some signal is contained in the stimulus presented, the technique allows to reveal visual cues that are actually not part of the stimulus' signal (e.g. [12, 15]). The avatar was produced using FACEGen (Singular Inversions Inc., 2009) and FACSGen [53]. FACEGen is a commercial tool that allows the creation of realistic 3D faces. FACSGen imports faces created with FACEGen and allows the linear manipulation of facial action units [14]. The face produced for the present experiment subtended a width of 6 degrees of visual angle (5.3 cm; distance between the participants' eyes and screen of 50 cm). Note that despite the fact that avatars may have the downside of having an artificial appearance, they offer the important advantage of being in control of the intensity to which the different action units are set. Here, the action units associated with the three core features of pain facial expressions were equally activated. Note also that the avatar is a computer-generated image; it does not represent a real human model.

2.1.1.3 Procedure. Each participant completed five blocks of 100 trials in which they were asked to rate to what degree each noisy face stimulus displayed on the computer screen corresponded to their representation of a facial expression of pain, using a visual scale ranging from 0 (does not correspond) to 10 (corresponds completely). These instructions entail that participants would give a higher rating to the stimuli that closely correspond to their mental representation of pain and differ from their mental representation of other mental states. On each trial, a random patch of sinusoidal white noise was generated (see [33] for more details on the noise generation) and added to the base face. The noisy face was then displayed in the center of the computer screen, below the scale, and remained on the screen until a response was given. Participants indicated their response by clicking, with the mouse, on the scale. Following the mouse click, the face disappeared and was replaced by a uniform gray screen for a duration of 500 milliseconds before the next face stimulus appeared.

2.1.1.4 Analysis: Computing the classification images. The Reverse Correlation technique allows to produce a classification image, which is the mathematical counterpart of the mental representation measured for each participant. In the present study, classification images were computed to reveal how a facial expression of pain was represented in the participant's mind. More specifically, separately for each participant, the ratings given to each of the 500 noisy faces were transformed into z-scores. The z-score value associated with each trial was then used as a weight to produce a weighted sum of the 500 patches of noise generated during the task. This procedure resulted in a classification image indicating which noise properties are correlated with the percept of pain facial expressions. Note that each patch of noise varied between ±1, with an average of 0; and the participant's rating transformed into z-score varied between between ±infinity, with an average of 0. Thus, each pixel in a participant's classification image may vary between ±infinity, with an average of 0.

2.1.2. Results

Figure 2 (left and middle panels) displays the average classification images across all participants, overlaid on the base face. These classification images show which facial properties decreased or increased the correspondence with participants' pain representation. Note that the "low correspondence" classification image is just the mathematical reverse of the "high correspondence" one; it is displayed to help the reader visualize how the mental representation differs from the background base face.

A statistical test was conducted to assess which areas of the classification image were significantly correlated with the perception of pain. First, the classification image of each participant was transformed into z-score values using the mean and the standard deviation of the null hypothesis, estimated using the values of the classification image pixels that fell outside the face area. They were then smoothed using a Gaussian kernel with a standard deviation of 12 pixels. The smoothing was necessary in order to use the Cluster test (see below), and the standard deviation of the filter used for smoothing was chosen to approximately match the size of a feature in a face. Note that the analysis was also performed with a smaller filter (standard deviation of 3 pixels) to make sure that the results described below were not an artifact of the filter chosen; the same areas were systematically revealed as significant.

A one sample t-test was performed on each pixel of the classification image to verify which ones were significantly related to the percept of facial expressions of pain. The statistical threshold was obtained using the Cluster test from the Stat4Ci toolbox [8], a statistical method based on the random fields theory that corrects for multiple comparisons (i.e. one t-test per pixel) by controlling for the family-wise error rate, while taking into account the fact that contiguous pixels are not independent (i.e. may be part of the same facial feature). As explained above, each pixel in a participant's classification image may theoretically vary between ±infinity, with an average of 0. Thus, for the one-sample t-tests, the null hypothesis was that the pixel values did not deviate from zero. The areas that were significantly associated with the percept (i.e. with values significantly deviating from 0) are revealed in red and green on the right panel of Figure 2 (T_{crit}=3.0, k=720, p<0.025). The red color indicates the areas that needed to be paler to increase the perception of pain, and the green color indicates the areas that needed to be darker to increase that perception. Together, these increases and decreases in luminance modulate the local contrasts and thus the features' appearance. The comparison of the left and middle panels to the right panel allows to make the bridge between the location of the features that were significantly related to the percept (right panel), and the change of appearance that occurred in those locations (left and middle panels).

The results indicate that the area between the eyebrows (Cohen's d = 1.1), that of the nose and of the mouth (Cohen's d = 0.95) needed to be darker to increase perception of the facial expression of pain. When darker, these areas make the folds between the eyebrows, the folds on the dorsal part of the nose and around the nostrils, and the folds above the upper lip appear more pronounced. Moreover, the temple area (Cohen's d = 1.3) needed to be paler to increase the perception of pain. This is likely linked to a change in appearance of the eyebrow angle (increasing the V shape appearance). Finally, perception of the facial expression of pain increased when the chin area (Cohen's d = 1.0) was paler. A paler chin area helps increase the contrast with the upper lip, making it appear darker.

2.1.3. Discussion.

Overall, an objective, pixel-based analysis indicates that the eyebrow angle, the folds between the eyebrows, the folds on the nose and the upper lip appearance were systematically linked with a change in the percept of pain facial expression. On the contrary, the area of the eyes, corresponding to a tightening of the orbital muscles surrounding the eyes, was not significantly related to a modulation of the pain facial expression percept. Nevertheless, a qualitative assessment of the pictures presented on the left and middle panels of Figure 2 suggests that the lids actually appear more tightened on the high than on the low intensity classification images. Thus, a subjective measure of the relative intensity at which each feature is perceived in the classification images presented on the left and middle panels of Figure 2 was collected.

2.2 Experiment 1b.

Although the pixel-based analyses reported above are very informative with regards to how different areas of the noise modulated the percept, it is possible that pixels outside an area of interest actually modulated the percept inside a region of interest. For instance, the analysis reported in the precedent section showed that perceived pain was higher when noise pixels were darker in the area between the eyebrows, and paler in the temple area. The impact of these changes may be, as proposed above, to increase the "brow lowering" appearance (i.e. folds between the eyebrows and V shape of the eyebrows). However, these changes may also influence the appearance of the "eye opening" feature. Therefore, a separate task was conducted to verify the relative changes subjectively perceived across the three facial features of pain expression.

2.2.1 Method.

2.2.1.1 Participants. Thirty-Two White participants (13 males) that did not take part in Experiment 1a took part in Experiment 1b. All participants were aged between 18 and 40 years old, and had normal or corrected-to-normal visual acuity. All procedures were carried out with the ethics approval of the Université du Québec en Outaouais.

2.2.1.2 Material and stimuli. Images of the average low and high pain mental representations (i.e. see Figure 2, left and middle panels) were presented side-by-side on a printed document. The task instructions were written above the images, and three scales ranging from 0 to 10 were presented below the images.

2.2.1.3. Procedure. The printed document was presented to the participant, who was first asked to rank three facial features as a function of how much they differed between the two images. The three facial features were described as follows: 1) "brow lowering" (changes in the angle of the eyebrows, in the folds between the eyebrows, or in the distance between eyebrows); 2) "eye narrowing" (tightening of the eyelids); 3) "nose wrinkling/upper lip raising". Following the ranking of the three features, participants were asked to rate, on the three scales ranging from 0 to 10, to what degree each of the three features were different in the two images.

2.2.2 Results.

In order to verify if differences were perceived in the degree to which each of the three features differed in the low and high pain mental representations, the frequency at which each possible sequence of ranks (i.e. six possibilities) occurred was calculated (see Table 1), and a chi-square was applied to verify if one sequence occurred more frequently than the others. The results indicate that the distribution of frequencies across the six possible orders indeed differed from the one expected by chance [$\chi^2(5) = 62.5$, $p<0.001$]. Many participants (20 out of 32) ranked "nose wrinkling/upper lip raising" as being the feature that underwent the biggest change between the low and high pain mental representations, followed by "brow lowering" and, finally, by "eye narrowing". Moreover, the amount of change perceived between the low and high pain mental representations, as measured with the scales, was significantly higher for the “nose wrinkling/upper lip raising” (M=8.41, SD=1.32) than for the “brow lowering” (M=5.31, SD=1.51) [t(31)=11.0, p<0.001; 95% CI: 2.52, 3.67] and “eye narrowing” features (M=4.03, SD=2.01) [t(31)=11.12, p<0.001; 95% CI: 3.57, 5.18]; and it was also higher for the “brow lowering” than for the “eye narrowing” features [t(31)=3.00, p=0.005; 95% CI: 0.41, 2.15].

2.2.3 Discussion

The results of Experiment 1 show that “brow lowering” and “nose wrinkling/upper lip raising” are more salient than “eye narrowing” in the mental representations of the participants tested in the present study. One could argue that the “eye narrowing” feature is much smaller and subtler than the “brow lowering” and “nose wrinkling/upper lip raising” features, and that this may have favor the utilization of the latter over the former. The results of a study using Reverse Correlation with basic facial expressions suggest that on the contrary, it is possible to reveal small and subtle features when they indeed represent the information coded in memory [22]. To make sure that subtle changes in the eye area were possible to reveal using the same base face and sinusoidal noise as used in the present study, a control task was also conducted, in which participants were asked to judge, on each trial, the degree to which the eyes were narrowed (see Supplementary Material, section 1). The results indicate that it is possible, suggesting that if participants had indeed relied on that feature during pain judgments, it would have come out as significant.

Moreover, it should also be noted that the analysis performed (one sample t-test) allows to conclude that the features revealed as significantly associated with the pain percept were relied on by a majority of participants; in other words, if participants had relied on randomly self-determined key features during the task, the features selected would have varied from one participant to the other, and it is unlikely that any feature would have come out as significant. This also means that some participants may have relied on the "eye narrowing feature", but this strategy was not frequent enough to be significantly associated with the percept across participants.

These results are congruent with previous studies showing that when individuals attempt to evaluate the pain experienced by someone else [36], or when they attempt to discriminate pain from other basic emotions [55, 56], they mostly rely on the "brow lowering" and "nose wrinkling/upper lip raising". Most importantly, these results allow to better understand why individuals mostly rely on these two features despite the "eye narrowing" feature being the most frequently observed in pain expressions [9, 29], and being the most informative feature to discriminate pain from other basic emotions [31, 55]. In fact, 1) the Reverse Correlation technique allows to reveal mental representations that do not necessarily perfectly overlap with the outside world, and 2) these mental representations interact with the information contained in the outside world in determining the information extracted for recognizing and interpreting pain facial expressions. The present results confirm that when they store mental representations of pain in memory, individuals in fact allocate weights to these three features that do not reflect their relative importance in the outside world; they indeed attribute more weight to the "brow lowering" and "nose wrinkling/upper lip raising" features than to the "eye narrowing" feature.

Thus, the results of Exp. 1 reconcile the discrepancy highlighted previously between the visual information contained in pain facial expressions, and the kind actually used by observers during pain decoding. One remaining question, however, is why observers would store the "brow lowering" and "nose wrinkling/upper lip raising" features more saliently in their mental representations? One potential explanation lies in the finding that these two core features of pain facial expressions do not code the same dimension of pain than the "eye narrowing" feature [28]. Many studies support the conceptualization of pain as a multidimensional experience, including an affective (encompassing the feelings of unpleasantness and other emotions related to the experience of pain) and a sensory (encompassing the location, intensity and quality of pain) dimension [34,40,50,51]. Interestingly, a study has shown that the affective dimension is encoded primarily in the “brow lowering” and “nose wrinkling/upper lip raising” movements. This is in line with findings regarding facial expressions of negative affective states, such as anger and disgust, which also encompass these two facial movements [23, 31]. In contrast, the sensory dimension of pain is primarily encoded in the tightening of the eyelids [28]. Of course, in facial expressions of pain, the facial cues associated with the affective and sensory dimensions are frequently observed together [29,36,43]. Indeed, although evidence support the independence of affective and sensory dimensions [e.g. 34,50,51], they are highly correlated [40,50]. Nevertheless, the results of Experiment 1 may reflect a mechanism whereby facial features most likely reflecting the negative affective valence are given more weight in how people imagine what expression is displayed by a person in pain. Instructions have been developed and proven efficient at targeting more specifically the affective or the sensory dimension of pain evaluation [42]. If Experiment 1’s results reflect a voluntary mechanism whereby observers allocate more weight to facial features reflecting the unpleasantness, rather than the physical intensity, of the experience of pain, it may be possible to modulate the relative saliency of the three core facial features using these instructions. Thus, Reverse Correlation was used in Experiment 2 to extract the mental representations of individuals when they are specifically asked to imagine what facial expression would be displayed by an individual experiencing a high level of affective or sensory pain.

3. Experiment 2

3.1 Experiment 2a

3.1.1 Method

3.1.1.1 Participants, Material and stimuli. Same as in Experiment 1a.

3.1.1.2. Procedure. First, the conceptual distinction between the sensory and affective dimensions of pain was explained to the participants using a French adaptation of the instructions developed by Price et al. (1983) and widely used since [e.g. 30, 48, 51, 63]. The English translation of the complete instructions that were given to the participants is provided as Supplementary material. All participants then took part in two tasks, which we will refer to as "Intensity" and "Unpleasantness", respectively. In the Intensity task, participants were asked to rate, on a scale ranging from 0 to 10, the perceived intensity of the pain that the individual presented on the computer screen appeared to experience; and in the Unpleasantness task, they were asked to rate, on a scale ranging from 0 to 10, the extent to which the pain that the individual presented on the computer screen appeared to experience seemed unpleasant. The order of the two tasks was counterbalanced across participants. In common with Experiment 1, each task comprised five blocks of 500 trials. On each trial, a random patch of sinusoidal white noise was generated and added to the same base face as the one used in Experiment 1. The noisy face was then displayed in the center of the computer screen, below the scale.

3.1.2. Results

Classification images were computed separately for the Intensity and Unpleasantness tasks, using the same procedure as described in Experiment 1a (see section 2.1.1.4). The classification images, overlaid on the base face, are presented on the left and middle panels of Figure 3.

First, for the purpose of comparison with Experiment 1a, a statistical test was performed separately on each classification image to verify which facial areas were significantly correlated with the pain percept in each task. More specifically, a one sample t-test was performed on each pixel of the Intensity and Unpleasantness classification images. The statistical threshold was obtained using the Cluster test from the Stat4Ci toolbox [8]. The areas that were significantly associated with the percept are revealed in red and green on the right panels of Figure 3 (T_{crit}=3.0, k=720, $p<0.025$). The red color indicates the areas that needed to be paler to increase the perception of pain, and the green color indicates the areas that needed to be darker to increase that perception. Similarly to the analogous figure in Experiment 1a, the comparison of the left and middle panels to the right panel allows to make the bridge between the location of the features that were significantly related to the percept (right panel), and the change in appearance that occurred at those locations (left and middle panels).

The results are very similar to those obtained in Experiment 1a. For both the Intensity and the Unpleasantness tasks, the area between the eyebrows (Cohen's d=0.95 and 1.34, for Intensity and Unpleasantness respectively), the nose and the mouth (Cohen's d=0.91 and 1.05, for Intensity and Unpleasantness respectively) needed to be darker to increase perception of the facial expression of pain. Moreover, the temple area needed to be paler to increase that perception. A paler chin area also increased perception of the facial expression of pain for the Intensity task, but this area did not reach significance for the Unpleasantness task. Note that an area outside of the face was significant in the Intensity classification image; this area is most likely a false positive. Nevertheless, because the presence of a false positive may shed doubt on the other areas revealed significant in the classification images, we conducted an additional, more conservative statistic test based on permutation and maximum statistics techniques ([54]; see Supplementary Material, section 2, for more details). Crucially, the result of this analysis again revealed that in the three classification images, the area between the eyebrows, the nose and the mouth needed to be darker to increase perception of the facial expression of pain. No area from the face contour was found significant.

Next, a repeated-measure Anova was performed to compare each pixel of the classification images across Experiment 1, the Intensity task and the Unpleasantness task. This allowed to verify if some facial features significantly differed in the pain facial expression percept as a function of the pain dimension attended to. The statistical threshold was obtained using the Cluster test from the Stat4Ci toolbox (T_{crit}=3.0, k=2005, p<0.05). No area reached the significance threshold (all p's > 0.5).

3.1.3. Discussion. An objective pixel-based analysis revealed no significant difference between the memory representations extracted in Experiment 1a, the Intensity task and the Unpleasantness task. However, as explained previously, it is possible that objective pixel-based analyses did not allow to capture qualitative differences between the classification images that might actually make them appear different depending on the task. The following experiment was thus designed to verify if a subjective evaluation of the features associated with the sensory and affective dimensions would highlight differences across the three tasks.

3.2 Experiment 2b

3.2.1 Method.

3.2.1.1 Participants. Thirty-two White participants (11 males) that did not take part in Experiment 1a, 1b, and 2a took part in Experiment 2b. All participants were aged between 18 and 40 years old, and had normal or corrected-to-normal visual acuity. All procedures were carried out with the ethics approval of the Université du Québec en Outaouais.

3.2.1.2 Material and stimuli. A paper document composed of three pages was created. On each page, images representing the average mental representation obtained in each of the three tasks (Exp. 1a, Exp. 2a Intensity and Exp. 2a Unpleasantness) were displayed side-by-side. The task instructions were written above the images, and three scales ranging from 0 to 10 were presented below the images.

3.2.1.3. Procedure. On each page, participants were instructed to focus on one facial feature (i.e. either “brow lowering”, “eye narrowing”, or “nose wrinkling/upper lip raising”). The order of the pages (and therefore of the facial feature on which to focus) was counterbalanced across participants. The order of the mental representations on a given page was also changed across participants (three different sequences were used). For each page, the participants were first asked to rank the three mental representations according to the degree to which the listed feature (i.e. either “brow lowering”, “eye narrowing”, or “nose wrinkling/upper lip raising”) was perceived. Once the ranking was completed, they were asked to rate, on the three scales ranging from 0 to 10, to what degree the feature was perceived in each of the three mental representations.

3.2.2 Results.

In order to verify if differences in the degree to which a given feature was perceived across the three memory representations were present, the frequency at which each possible sequence of ranks (i.e. six possibilities) occurred was calculated (see Table 2), and a chi-square was applied to determine if one sequence occurred more frequently than the others. The results indicate that this was not the case: [$\chi^2(5) = 9.25$, p=0.10], [$\chi^2(5) = 7.38$, p=0.19], [$\chi^2(5) = 2.50$, p=0.78] for the “brow lowering”, “eye narrowing” and “nose wrinkling/upper lip raising” features respectively (the Bonferroni corrected threshold being $p < 0.017$). Moreover, the ratings allocated to each of the three features (see Table 3) were compared across the three mental representations with repeated-measure Anovas. The effect of the type of mental representation (i.e. “Basic”, “Intensity” and “Unpleasantness”) was significant neither for the “brow lowering” [F(2, 62)=0.93, p=0.43], for the “eye narrowing” [F(2, 62) = 1.35, p=0.27], nor for the “nose wrinkling/upper lip raising” [F(2, 62) = 0.05, p=0.95].

3.2.3 Discussion

The results of Exp. 2 showed that the mental representation of pain facial expressions does not change when attention is specifically directed towards either the affective or the sensory dimension. This suggests that the results obtained in Exp. 1 were not obtained because individuals voluntarily allocate more weight to the affective dimension when evaluating others’ pain. In fact, even with instructions specifically designed, validated, and widely used to direct attention towards either the sensory or affective dimension [42], the facial areas on which more weight was attributed in the mental representations remained the same.

4. General discussion

This study aimed at verifying what features of pain facial expressions are represented in memory. Exp. 1 indicates that the “brow lowering” and “nose wrinkling/upper lip raising” features were stored more saliently than the “eye narrowing” feature. Interestingly, these two features have been shown to be more strongly associated with negative affective states in general and with the affective dimension of pain in particular [28]. Exp. 2 indicates that a higher weight is allocated to these two features even when participants are asked to attend to the sensory dimension.

4.1 More weight attributed to the "brow lowering" and "nose wrinkling/upper lip raising" features.

The finding that more weight is attributed to the "brow lowering" and "nose wrinkling/upper lip raising" features in the mental representations of pain is congruent with studies that have looked into the facial cues extracted and used to judge pain intensity in others [36], or to discriminate it from other facial expressions [55]. It was shown that the "brow lowering" feature is the best predictor of perceived pain when observers are asked to rate the pain experienced by strangers based on their facial expression [36]. It was also shown that the area between the eyebrows and that of the mouth were used to discriminate pain from the six basic facial expressions of emotions [55]. The latter result was all the more intriguing, since an model observer indicated that the best strategy would have been to use the "eye narrowing" rather than the "brow lowering" feature. The high informativeness of the "eye narrowing" feature is also congruent with studies showing that among the core facial units of expressions of pain, this feature is the most prominent one [9,29], and it does not occur to similar degrees in other negative emotions, therefore allowing to distinguish pain from them [31]. This finding revealed a discrepancy between the distinctive information contained in facial expressions of pain, and the information used by humans to recognize it. As explained in the Introduction, the information used to recognize an object of the outside world lies in the intersection between the visual information contained in the object, and the memory representation of that object. The present results therefore offer a potential explanation for the discrepancy highlighted above: the "brow lowering" and "nose wrinkling/upper lip raising" features are more salient than the "eye narrowing" feature in the mental representation of facial expressions of pain.

Interestingly, the two features that were most saliently coded in the mental representations are the ones that reflect negative valence and, with regard to pain, its affective dimension [28]. This may indicate that this dimension is more important in the interpretation of pain perceived by another. The results of Exp. 2 indicate that, if the affective dimension is indeed given more weight, it is not a voluntary process. In fact, the relative weight attributed to the three features in representation does not change as a function of the dimension towards which attention is driven.

4.2. Pain representation is not affected by the dimension towards which attention is directed.

The finding by Kunz et al. (2012) that information about the sensory and affective dimensions of pain is transmitted through independent facial cues suggests that the face is finely tuned for pain communication. If the facial expression of pain distinctly encodes each dimension of pain, one could have expected the human observer’s visual strategies to be sensitive to both kinds of information. The results of Exp. 2 suggest that, in terms of mental representations, individuals do not knowingly make the difference between the facial expression of someone experiencing highly unpleasant pain or someone experiencing highly intense pain. Of course, this interpretation relies on the assumption that the participants understood the instructions used to drive attention more specifically to the affective or to the sensory dimension of pain; this assumption is rather reasonable, since the instructions have been proven efficient in numerous studies in the past [e.g. 41,49,51,63,64,65]. Most importantly, even if the participants had not understood appropriately, one can at least be confident that the instructions were given in a way to make participants biased for the affective dimension, which could have been an interpretation of the present results. Rather, Exp. 2’s results confirm that the same features are given the highest weight regardless of the task instructions.

This result makes sense given that, most of the time, facial cues related to both dimensions are available at once in the expression of someone experiencing pain. In fact, although the affective and sensory dimensions are independent [34,50,51], they are highly correlated [40,50]. Moreover, to develop an understanding of which facial cues are associated with one dimension of pain or the other, observers would need to have information about how pain expressed through facial cues related to each dimension is respectively experienced. However, in day-to-day interactions, people experiencing pain do not describe their experience in terms of its affective and sensory components; they most likely just communicate their global experience.

The present results suggest that individuals automatically allocate more weight to facial features reflecting negative affect and the unpleasantness (rather than physical qualities) of the experience of pain. More research will be needed to fully understand this finding, but a few potential explanations may be proposed. For one, it is possible that the human visual system has evolved to mostly extract information from features associated with the affective dimension of pain because the amount of suffering (i.e. pain unpleasantness) experienced by someone may be a better indicator of the urgency of help required. Another potential explanation is that the processing of the “eye narrowing” feature, which is also present during authentic happiness expressions [13], is inhibited to help with the disambiguation between a positive and a negative state, a distinction that is important to make quickly and accurately for obvious evolutionary reasons. In line with this hypothesis, studies have shown that facial expressions associated with negative affect are also observed when someone suffers [21,32], and are more frequent in people reporting higher levels of pain [32]. Thus, attributing more weight, in mental representations, to facial features reflecting both pain and negative affects accompanying pain may be an efficient strategy. An alternative possibility lies in the finding that empathizing with someone else’s pain mostly involves brain areas usually associated with the affective dimension of pain [49]. Being in a state of affective pain may activate the facial muscles associated with that state, and facilitate the visual processing of these facial cues. In fact, it has been suggested that understanding an action requires the activation of the neural network involved in the production of the action per se [45]; and many studies have shown that recognition of facial expressions is in part achieved through facial expression simulation (see [13] for a review).

4.3 Limits of the present study.

The sample used in the present study was unbalanced with regard to gender and therefore did not allow to evaluate gender effects on pain mental representations. Future studies should investigate the impact of the encoder's and decoder's gender [25] on the mental representation of pain facial expressions. Based on previous studies, differences may be expected. For instance, different patterns of cerebral activation have been found when viewing male vs. female pain faces; the lower frequency of pain expressions by males and their stronger association with potential threats to the observer have been proposed as potential explanations for this finding [59]. Moreover, some have shown a greater involvement of the neural mechanisms related to empathic responses in female than in male observers during pain observation [67]. An investigation of gender effects will potentially provide us with more information with regards to the relative use of the different facial cues when processing pain facial expressions. Another potential limitation of the present study was the use of an avatar face. Nevertheless, the results are highly congruent with the ones obtained by studies using real faces to investigate the facial features used to decode pain facial expressions [36, 55]; thus, the use of an avatar in the present study is unlikely to have dramatically impacted the findings.

5. Conclusion.

The present study is the first to directly verify what facial features are stored in people's mental representation of pain facial expressions. The results indicate that individuals store the "brow lowering" and "nose wrinkling/upper lip raising" features more saliently than the "eye narrowing" feature. Most importantly, this finding is congruent with the discrepancy observed between the facial features most prominently contained in pain expressions and the ones on which observers rely most to decode pain. Interestingly, this pattern of results does not change as a function of the pain dimension towards which attention is directed, suggesting that it does not reflect a conscious and voluntary mechanism favoring the affective dimension of pain. More research will be needed to clarify the potential behavioral consequences of this under-representation of the “eye narrowing” feature, and to understand the mechanisms that underlie the construction of mental representations that over-emphasize the facial features associated with the affective dimension of pain.

Acknowledgments

We would like to thank Gabrielle Dugas and Valérie Plouffe for their help with data collection. This work was supported by a grant from the Social Sciences and Humanities Research Council (SSHRC) to Caroline Blais, Daniel Fiset, Stéphanie Cormier and Miriam Kunz, and by an undergraduate scholarship from the Natural Sciences and Engineering Research Council of Canada (NSERC) to Hana Furumoto-Deshaies. The authors have no conflict of interest to declare.

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FIGURE CAPTIONS

Figure 1. Example of the steps involved in the creation of three stimuli.

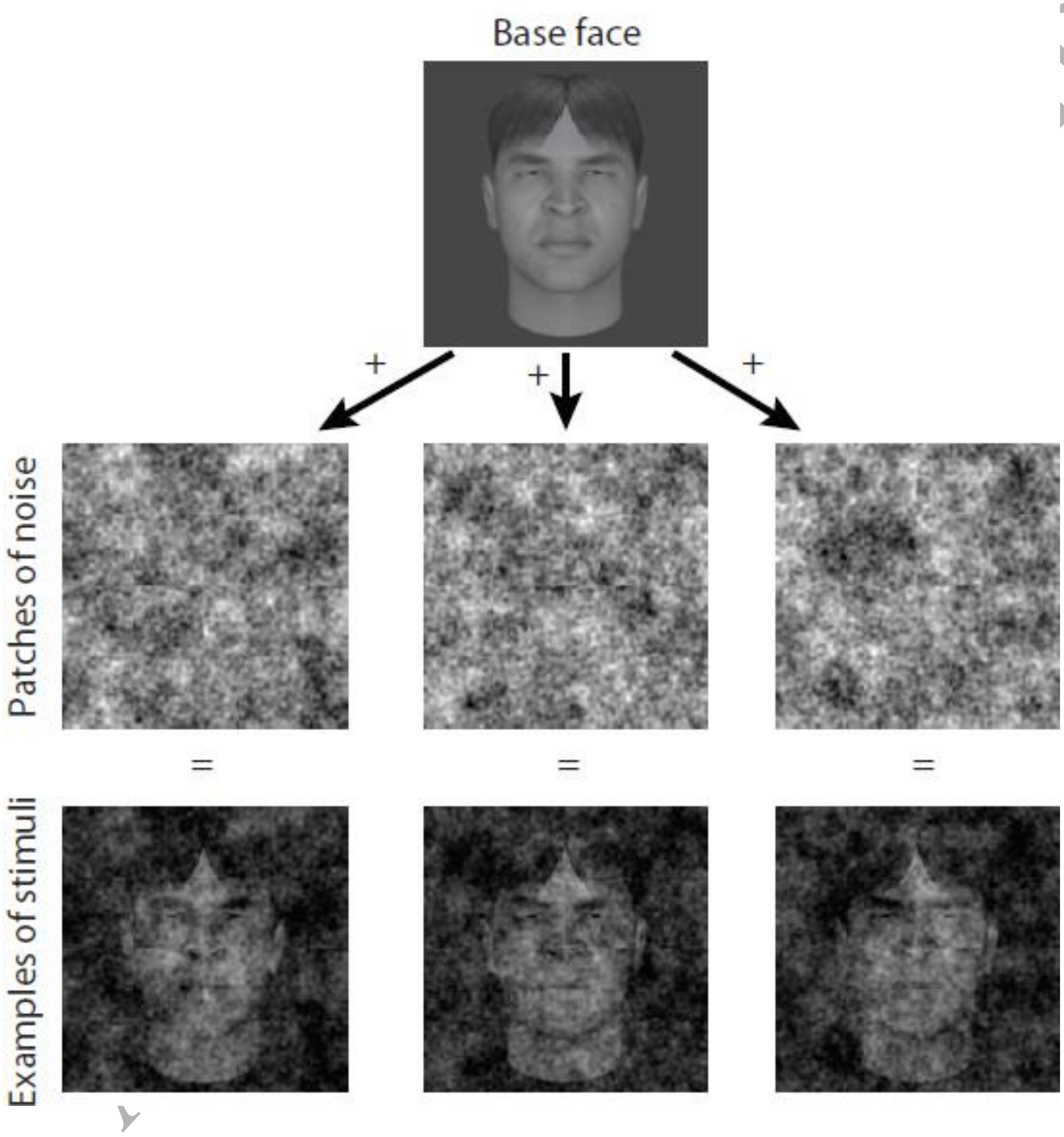

Figure 2. The left and middle panels display the classification images overlaid on the base face: the low correspondence classification image is simply the mathematical inverse of the high correspondence classification image. The right panel displays the clusters of facial information that were significantly correlated with the percept of pain expression.

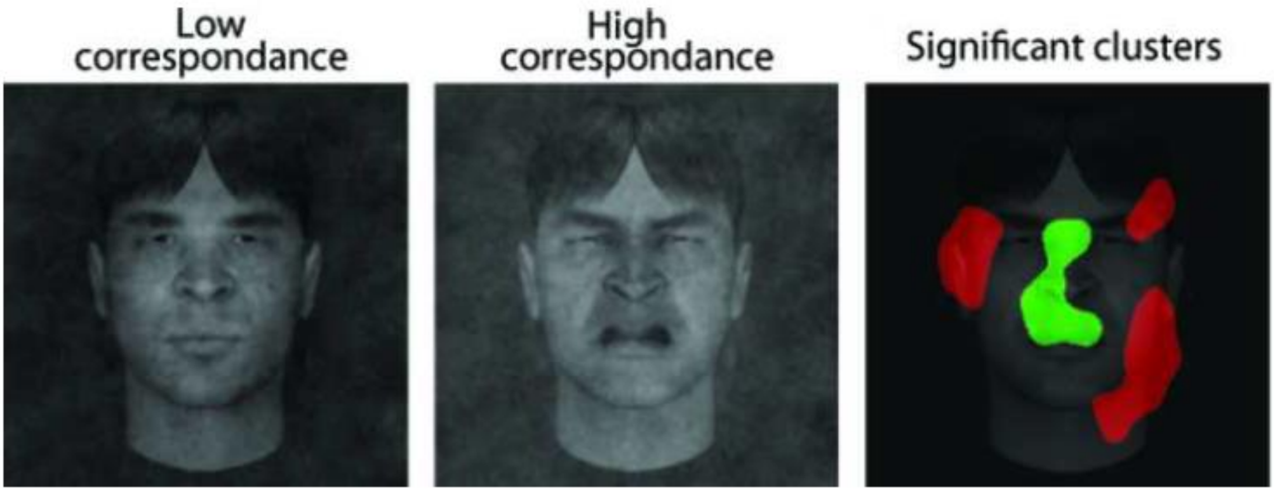

Figure 3. The left and middle columns display the classification images overlaid on the base face, for each task: the low pain classification images are simply the mathematical inverse of the high pain classification images. The right columns display the clusters of facial information that were significantly correlated with the percept of pain expression.

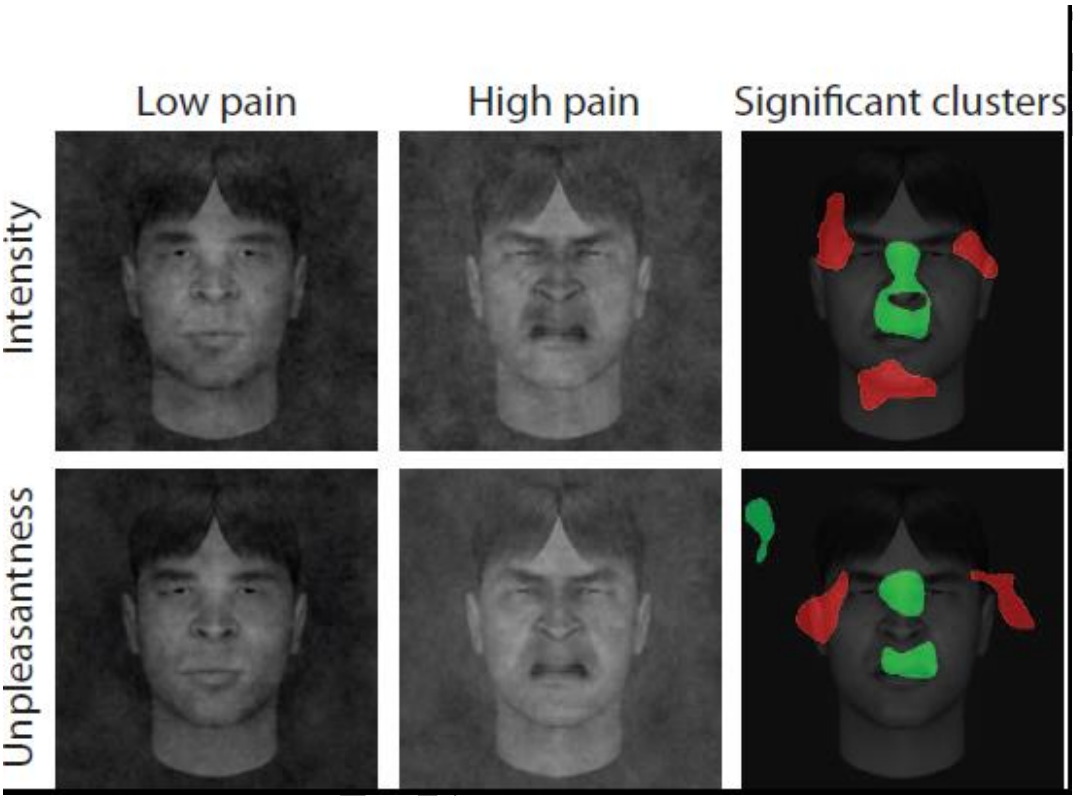

Table 1. *Frequency of each possible order.*

Possible orders	Frequency
Brow > Eyes > Mouth	0
Brow > Mouth > Eyes	2
Eyes > Brow > Mouth	0
Eyes > Mouth > Brow	0
Mouth > Brow > Eyes	20
Mouth > Eyes > Brow	10

Table 2. *Frequency of each possible order. B=Basic, I=Intensity, U=Unpleasantness.*

	Brow lowering	Eye narrowing	Nose wrinkling/upper lip raising
B > I > U	7	7	5
B > U > I	10	4	5
I > B > U	2	5	6
I > U > B	3	2	8
U > B > I	3	10	3
U > I > B	7	4	5

Table 3. *Average ratings (standard deviations between parentheses) of each feature across the three tasks.*

	Basic	**Intensity**	**Unpleasantness**
Frown	6.59 (1.97)	6.75 (1.92)	5.97 (2.21)
Eye narrowing	6.81 (1.93)	6.94 (2.34)	6.56 (2.29)
Nose wrinkling/upper lip raising	6.34 (2.40)	6.53 (2.38)	6.31 (1.94)

HIGHLIGHTS

- Most salient features in mental representation of pain facial expressions.
- Brow lowering and nose wrinkling features more salient than eyes narrowing.
- Pattern stable whether attention is directed to affective or sensory dimension.